NSWC TR 90-41

VIBRATION TESTING OF FIBER OPTIC COMPONENTS

BY G.D. BROWN J.P. INGOLD S.E. SPENCE
COMBAT SYSTEMS DEPARTMENT

MARCH 1990

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FOREWORD

This test program is a portion of a task statement to investigate the performance of commercial fiber optic components in military environments. The intent of this program is to identify those component designs that can be transitioned to military grade products with minimal cost and design change.

This work is done in support of the Naval Sea Systems Command (NAVSEA) 56ZC Fiber Optic Program Office and is sponsored by NAVSEA 56ZC under work requests N0002488WX14327 and N0002488WX02516.

The authors would like to acknowledge the many hours of engineering assistance and dedication shown by F. Needham and C. Rose.

This report was reviewed by A. F. Riedl, Head, Combat Systems Technology Branch; and R. N. Cain, Head, Engineering and Technology Division.

Approved by:

CARLTON W. DUKE, JR., Head
Combat Systems Department

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INTRODUCTION

This report documents the results of vibration testing of fiber optic connectors and splices conducted at the Naval Surface Warfare Center (NSWC) from 22 July to 1 August 1988. The objective of this report is to evaluate the performances of these components in a vibration environment according to their generic construction. Additionally, the detailed fiber optic component test procedures, the test facilities , and the component preparation and test setup are evaluated. A brief review of previous vibration testing is included and general trends in the performance of generic designs are expanded upon. The test results are compared to current specifications for fiber optic components aboard naval surface ships and recommendations are made for the concluded best generic designs.

The Naval Sea Systems Command (NAVSEA) Fiber Optic Program Office was established to accelerate the introduction of fiber optic technology into the U.S. Navy, concentrating primarily on surface combatants. The fiber optic environmental test program was developed to assist the Fiber Optic Program Office in the development of fiber optic component specifications and standards. NSWC was tasked by the Fiber Optic Program Office to develop an overall fiber optic component test plan, review the literature for previous test documentation and results, develop detailed environmental test procedures, and perform environmental testing of fiber optic components and analysis of the results, providing recommendations for the component specifications and standards. This report delivers the recommendations for the fiber optic connector and splice designs and their associated performances, based on the vibration tests conducted and information available from published literature. Additional reports detailing component performances in other environments are in process.

TEST PROCEDURES

Test procedures were developed by NSWC for vibration testing of optical connectors (see Appendix A). These procedures were used in the testing of both the connectors and the splices. In order to combine the correct military environmental extremes with the appropriate fiber optic measurement and handling procedures, these test procedures were assembled from several other procedures including MIL-E-16400, MIL-STD-810, MIL-STD-167, MIL-STD-202, Electronic Industries Association (EIA) 455-13, and EIA-455-20. These NSWC developed test procedures now include modifications that were made to the original procedures during the course of the testing.

EQUIPMENT SETUP

Each component was monitored for changes in optical transmittance as shown in Figure 1. The light sources used were light emitting diodes (LEDs) for multimode components and laser diodes for singlemode components. The test wavelength was 1300 nm. The couplers used were

1 by 8 and constructed by the twisted biconical taper method (multimode) or by concatenating 1 by 2 couplers made by the twisted biconical taper method (singlemode). Fifty micron core couplers were used for all of the multimode components and singlemode couplers were used for the singlemode components. A high-order mode stripper was used on the singlemode components to eliminate errors due to cutoff related problems and second mode power.

The modal distribution of the multimode components was not monitored although it is expected that the distribution was intermediate between an overfill and a 70/70 (70-percent spot size and 70-percent numerical aperture) for fiber sizes above 50 micron and was a poor overfill for 50-micron sizes.

One leg of each coupler was used as a source monitor for each of the components tested using that coupler. The output of each component and the source monitor output was monitored using large area, intermediate frequency response (500 kHz), germanium detectors. The output of the detectors was linear with optical power over a range from 500 nW to 50 μW. The output of the detectors was amplified up to approximately 1V, using the amplifiers, and recorded on magnetic tape. The equipment used in the tests is listed in Table 1.

TABLE 1. EQUIPMENT USED

Item	Manufacturer	Model No.
Source	Intelco	110
Source	Photodyne	1700-1300
Coupler	Gould	Series E
Coupler	Canstar	PCS
Detectors	NTL	-
Amplifier	Trig-Tek	205A
Tape Recorder	Honeywell	101
Tape Recorder	Sabre	III
Vibration Table	Team	-

ENVIRONMENTAL TEST LIMITS

The environmental test limits for this test were derived from existing standards for Navy platforms. The thrust of this test effort is for shipboard applications so the general specifications used were MIL-E-16400 and MIL-STD-810. As an initial effort, an all inclusive set of vibration limits was assembled to represent all possible vibrations that a component would experience during its lifetime. This list includes standard shipboard low- frequency sinusoidal vibration, air- and ground-transportation vibration, and random shipboard vibration. The environmental test limits are listed below.

Standard Shipboard Vibration

The test sample was subjected to type I sinusoidal vibration consisting of the three following tests: the exploratory vibration test, the variable frequency test, and the endurance test.

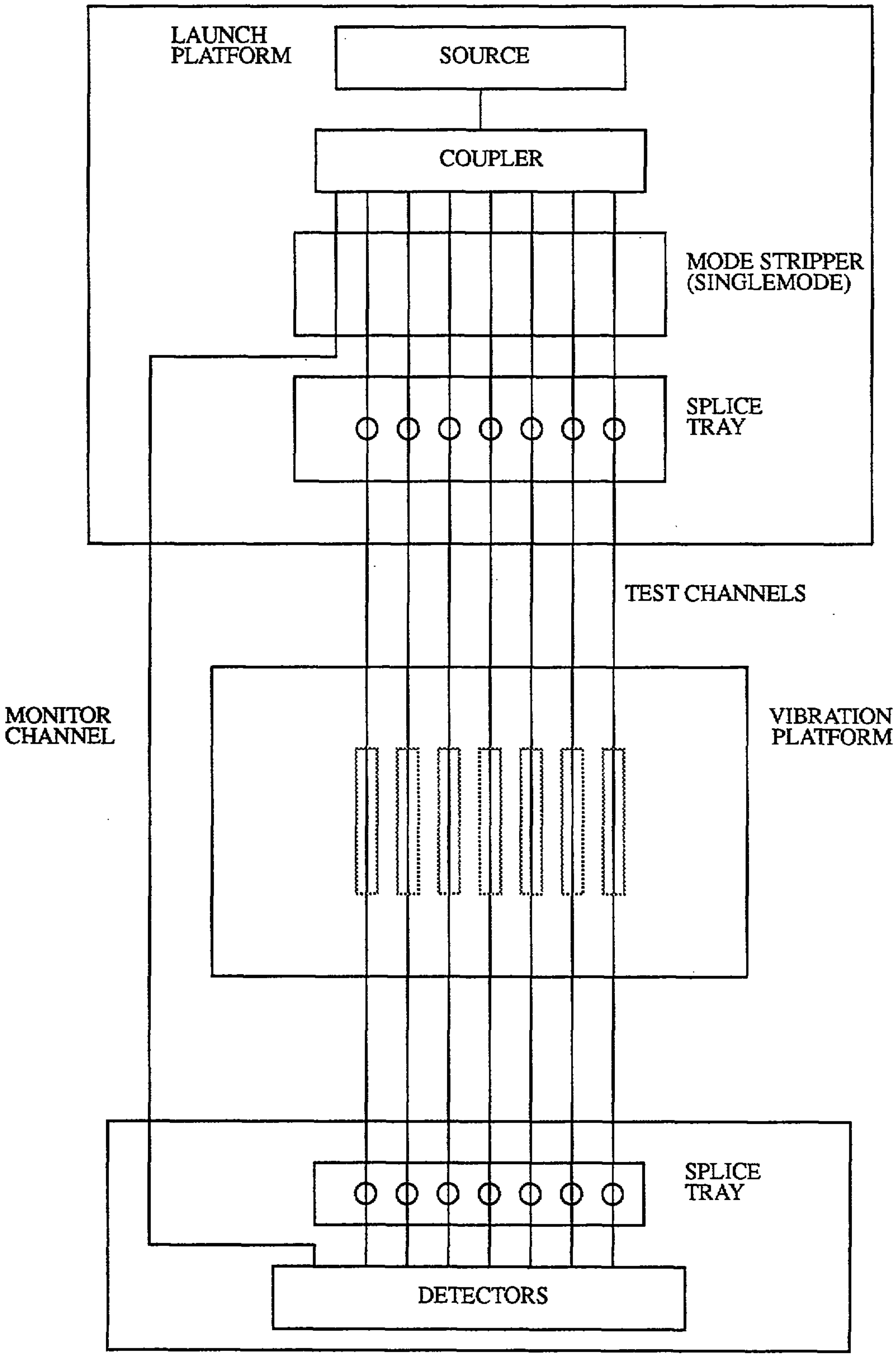

FIGURE 1. VIBRATION TEST EQUIPMENT SETUP

Exploratory Vibration Test. The test sample was vibrated from 4 to 50 Hz in discrete frequency intervals of 1 Hz with a 15-sec dwell at each freqency. The frequencies at which resonances occurred were noted.

Variable Frequency Test. The test sample was vibrated from 4 to 50 Hz in discrete frequency intervals of 1 Hz with a 5-min dwell at each frequency.

Endurance Test. The test sample was vibrated for a total period of 2 hr at 50 Hz.

Transportation Vibration

The test sample was vibrated from 10 to 500 Hz along each of the 3 mutually perpendicular axes for 30 min each (1 hr and 30 min total). The vibration levels were 1.5 g from 10 to 70 Hz, 0.006-in. double amplitude from 70 to 108 Hz and 3.5 g from 108 to 500 Hz.

Random Shipboard Vibration

The test sample was vibrated along each axis for 30 min from 10 to 2000 Hz with an rms level of 10.92 g.

COMPONENT PREPARATION AND MOUNTING

The components used in this test were commercially available components and, with limited exceptions, were tested as received from the manufacturer. An attempt was made to obtain already assembled components from the manufacturers to maximize the quality of the components tested since the manufacturers have more expertise in assembling their own components. When this was not possible, unassembled components were assembled using the manufacturer's recommended assembly procedures and, if at all possible, was done under the supervision of a manfacturer's representative. No additional component preparation or preconditioning was attempted; however, the complete test setup was preconditioned at ambient temperature prior to each test to allow all of the cables, run as part of the test set, to relax and stabilize before the actual test was started. The preconditioning period for the test was approximately two days.

The mounting of the components varied slightly between the different items. Panel mount connectors were mounted to angle plates bolted perpendicular to the aluminum vibration plate. Connectors and splices that were not panel mount were tightly affixed to the plate with cable ties. In all cases, the component and the pigtails leading to and from the component were tightly tethered to the vibration plate.

DATA COLLECTION AND ANALYSIS

Data were collected using an analog tape recorder in an FM format. After the test, the stored data were digitized and saved in an IBM compatible format. The data were then put into spreadsheet format and the relative transmittances of each component during the test calculated. No averaging or smoothing was used.

RESULTS

The vibration test results are shown in Table 2. The table is split into sections to differentiate between component types. Component type is used as a synonym for generic component design. It is evident from the table that, with one exception, the vibration test caused no measureable effect (either permanent damage or analog modulation) on the components tested. These observations are consistent with results reported by other groups performing vibration tests (see Table 3).

TABLE 2. VIBRATION TEST RESULTS

Component	Description	Identification	Analog Modulation (dB)	Permanent Change (dB)
Connector	Ferrule Type (MM)	86490	<0.1	<0.2
		16837	<0.1	<0.2
		01430	<0.1	<0.2
	Ferrule Type (SM)	62950	<0.1	<0.2
		60908	<0.1	<0.2
		08667	<0.1	<0.2
		40295	<0.1	<0.2
		36833	<0.1	<0.2
		73003	<0.1	<0.2
		28257	0.25	<0.2
	Array (SM)	81982	<0.1	<0.2
	Pin and Socket (MM)	92564	<0.1	<0.2
Splice	UV Split Glass Tube (MM)	16342	<0.1	<0.2
	UV Split Glass Tube (SM)	33699	<0.1	<0.2
	Fusion (MM)	01176	<0.1	<0.2
	Array (SM)	44643	<0.1	<0.2
	UV Glass Tube (SM)	25855	<0.1	<0.2

Analog modulation effects with a peak-to-peak amplitude of less than 0.1 dB and permanent changes in optical transmittance of less than 0.2 dB were not considered significant in this context.

TABLE 3. PREVIOUS VIBRATION TEST RESULTS

Component	Type	Extremes	Effect	Reference
Connector	Pin and Socket	12 c, 15 g 10 to 2000 to 10 Hz 20 min/c	<2.0 dB	1
Connector	Pin and Socket	12 c, 15 g 10 to 2000 to 10 Hz 20 min/c	<2.0 dB	2
Connector	Ferrule	10 c 10 to 500 Hz	none	3
Coupler	Fused	10 c, 5 g 5 to 500 Hz 20 min/c	<0.3 dB	4
Coupler	PCS	10 to 10000 Hz, 10 g 350-Hz Dwell, 300 g	none	5
Coupler	Fused	9 c, 2 g 10 to 2000 to 10 Hz 20 min/c	none	6
Connector	Mechanical Crimp	12 c 10 to 500 Hz	none	7

DISCUSSION

The results given in Table 2 do not require much explanation, so only a few notes will be mentioned. Due to problems with noise generated in the amplifiers, analog modulation was not directly evident in the data. It was inferred from the data, however, when the peak-to-peak noise level in a channel changed significantly during some portion of the test. The value of 0.25 dB given for component 28257 represents the difference between the peak-to-peak noise level observed before the random vibration test and the peak-to-peak noise level observed during the random vibration test. It should also be noted that other components did show a possible increase in noise level during the random vibration test, but the magnitudes were so small (<0 .05 dB) that they were not judged to be meaningful.

The test procedures that were originally developed for this test allowed both LEDs and laser diodes as sources for the multimode components. Prior to the conducting of the actual tests, it was found that the laser diode sources were inappropriate for use in the characterization of multimode fiber optic components. Variations in the transmitted optical power due to the modal sensitivity of the splitters and the test samples themselves tended to dwarf the effect of vibration on the test sample.

As a final note, the recommendations in this report address only the vibration performance of the components and do not include such considerations as human factors or mechanical characteristics.

CONCLUSIONS AND RECOMMENDATIONS

All of the connector and splice types tested, with one exception, showed minimal effect from vibration and, therefore, are suitable for use in the Navy shipboard vibration environment. Furthermore, based on the data, connectors and splices intended for Navy use should not experience changes in optical transmittance greater than 0.2 dB during or after vibration testing. As a final note, the random portion of the vibration testing was judged to be the harshest and could be used to screen out unsatisfactory connectors and splices without the added expense of additional testing.

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APPENDIX A

VIBRATION TEST PROCEDURE

PURPOSE

The purpose of this test is to determine the response of optical connectors to different types of vibration (shipboard sinusoidal, transportation, and random). Such vibrations are typical of what the connector will be subjected to prior to, during, and after deployment aboard navy vessels.

ENVIRONMENTAL REQUIREMENTS

ENVIRONMENTAL CONDITIONS AND RANGES[A-1]

Shipboard Vibration[A-2]

The connector shall be tested in accordance with MIL-STD-167 as specified by MIL-E-16400. The test sample shall be subjected to type I vibration and shall endure three types of tests: the exploratory vibration test, the variable frequency test, and the endurance test.

Exploratory Vibration Test. This test detects the presence of resonances in the test sample for each of the three axes and shall be conducted as follows. The test sample shall be vibrated from 4 to 50 Hz. The frequency shall be changed in 1-Hz intervals and maintained at each frequency for 15 sec. The frequencies and locations at which resonances occur shall be noted. From 4 to 33 Hz, the table vibratory single amplitude shall be 0.020±0.004 in. (peak to peak). From 34 to 50 Hz, the table amplitude shall be 0.006 (+0,-0.002 in. (peak to peak)).

Variable Frequency Test. The test sample shall be vibrated from 4 to 50 Hz in discrete frequency intervals of 1 Hz at the amplitudes shown in Table A-1 for all 3 axes. At each integral frequency, the condition shall be maintained for 5 min.

TABLE A-1. VIBRATORY DISPLACEMENT

Frequency Range (Hz)	Table Amplitude (in. peak to peak)
04 to 15	0.060±0.012
16 to 25	0.040±0.008
26 to 30	0.020±0.004
34 to 40	0.010±0.002
41 to 50	0.006+0.000 -0.002

Endurance Test. The test sample shall be vibrated for a total period of 2 hr at each of the resonant frequencies. If no resonance is observed, the test shall be performed at 50 Hz. The amplitudes of vibration shall be as given in Table A-1.

Transportation Vibration[A-3,A-4]

This test shall simulate the vibration associated with the shipping and handling of fiber optic connectors. The test sample shall be subjected to simple harmonic vibration as follows. The test sample shall be vibrated along each of the 3 mutually perpendicular axes for 30 min each (1 hr and 30 min total). The frequency range of 10 to 500 Hz shall be covered by cycling at a logarithmic rate allowing 15 min for each 10 to 500 to 10 Hz sweep. The tolerance on time and frequency shall be ±3 percent. The vibration amplitude shall be maintained at 0.06±0.006 in. (peak to peak).

Random Vibration[A-3,A-4]

This test shall simulate the random vibration experienced by the fiber optic connector during aircraft carriage and shipboard installation. The connector shall be subjected to the following random vibration along each of the three mutually perpendicular axes. The Power Spectral Density (PSD) shall be maintained at a constant level of 0.06 g^2/Hz from 10 to 2000 Hz. The roll-off below 10 and above 2000 Hz should be at the maximum rate provided by the test equipment, but shall not be less than 18 dB per octave. The PSD shall be maintained to within ±3 dB when analyzed with a frequency resolution of 50 Hz or less. The overall acceleration shall be maintained to within ±10 percent. The test duration shall be 90 min (30-min per axis). The tolerance on frequency and time shall be ±3 percent.

ENVIRONMENTAL PARAMETERS TO BE MONITORED

The following parameters shall be monitored during the test:

a. Frequency of vibration

b. Ambient temperature

TEST SAMPLE

DESCRIPTION

Connectors

The test sample shall consist of a mated pair of connectors terminated to optical cables as specified by the manufacturer. The cable length shall be at least 7 m on each side of the

connectors. The test length shall be the 50-cm section of the test sample that contains the connector at its approximate midpoint.

FIXTURE

Two types of fixtures shall be used depending on the mounting technique of the test sample: panel or nonpanel mount. A panel mount test sample shall be mounted on a plate such that there is at least 10 cm of clearance between the test sample and any other object (excluding the plate to which it is mounted). This plate shall be mounted perpendicular to a secondary plate (see Figure A-1), which will be mounted on the vibration table.

The fixture for the nonpanel mount test sample shall consist of a flat plate to which the test sample will be secured using cable ties and/or cable clamps. The test sample shall be mounted such that there is at least 10 cm of clearance between the test sample and any other object on the plate. The plate will be mounted on the vibration table.

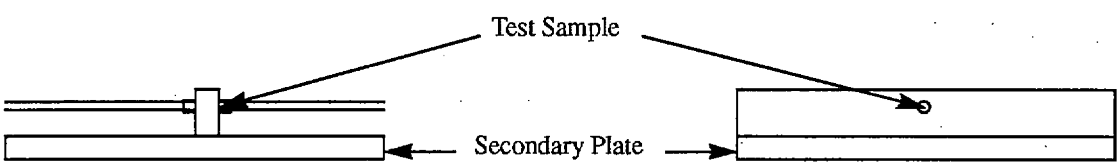

FIGURE A-1. PANEL MOUNT CONNECTOR FIXTURE

TEST PROCEDURE

PARAMETERS

The following parameters shall be monitored:

a. Structural integrity

b. Physical dimensions

c. Optical transmittance

PARAMETER MEASUREMENT

Visual and Mechanical Inspection[A-5]

This inspection is conducted to verify the structural integrity of the fiber optic connector. It shall include documentation of any gross abnormalities (e.g., cracks or breaks in the connector

exterior) that may exist in the connector prior to and after exposure to the environment. If an abnormality is quantifiable, the physical dimensions of the abnormality shall be measured. A written and photographic record of the inspection shall be maintained.

1. Mark the test sample to provide reference points for the photographic and written records

2. Examine the test sample for any abnormalities, including the following:

   -- Blisters, cracks, splits, dents, scratches or other deformations of any part of the test sample

   -- Loosening of the connector halves

   -- Loosening of the optical termini

   -- Damage inflicted on the connecting cable by the test sample

Change in Optical Transmittance

This test is conducted to determine the change in optical transmittance induced in the test sample or its constituent waveguides by the environment.

Equipment Setup

1. Connect the input of the coupler to the optical source:

   -- For MM, use an LED source

   -- For SM, use either an LED or laser source

2. Splice each fiber of the test sample onto an output of the coupler

3. Place each completed splice in a splice tray or holder

4. For SM, wrap the fibers of the test sample twice around a 1-in. diameter mandrell at the launch end of each fiber

5. Splice the exit end of each fiber of the test sample onto a connector pigtail

6. Place each completed splice in a splice tray or holder

7. Connect each pigtail to an optical input of an optical detector

8. Connect the monitor output of the optical coupler to an input of an optical detector

9. Connect the electrical output of each active detector to an input of the amplifier

10. Connect the output of each amplifier to an input of the magnetic tape recorder

Measurement Procedure

1. Measure and record the voltage level of the detectors

2. Calculate the change in the optical transmittance as follows:

$$\Delta P_i = 10\log\left[\frac{V_i V_{mon_o}}{V_o V_{mon_i}}\right] \qquad (dB)$$

where V_i is the measured test voltage level, V_o is the initial voltage level, V_{mon_i} is the measured monitor voltage level, and V_{mon_o} is the initial monitor voltage level. (The detector/amplifier/tape recorder must have the property that zero volts implies zero optical power. If this is not the case, offset voltages must be added to each of the voltages before using the above equation.)

TEST SEQUENCE

The following is a chronological listing of the steps required to complete this test.

Preexposure

The preexposure test sequence shall be as follows:

1. Conduct a preexposure visual and mechanical inspection on the test sample

2. Mount the test sample on the test fixture

3. Turn on the test equipment and allow it to warm up for 15 min

4. Ensure that the output voltage of each detector corresponds to its linear optical-to-electrical operating range

Exposure

The exposure test sequence shall be as follows:

1. Conduct the shipboard exploratory vibration test on each principal axis as follows:

   -- Conduct the vibration test as specified; monitor the optical transmittance for 5 sec prior to the test and for 5 sec after the test

-- Conduct a visual examination over the same area as previously inspected

2. Conduct the shipboard variable frequency test on each principal axis as follows:

   -- Conduct the vibration test as specified; monitor the optical transmittance for 5 sec before and after the test; monitor the optical transmittance for 5 sec at a minimum of 5-integral frequencies during the test.

   -- Conduct a visual examination over the same area as previously inspected

3. Conduct the shipboard endurance test on each principal axis as follows:

   -- Conduct the vibration test as specified; monitor the optical transmittance for 15 sec before and after the test; monitor the optical transmittance for a 5-sec interval every 30 min during the test

   -- Conduct a visual examination over the same area as previously inspected

4. Conduct the transportation vibration test on each principal axis as follows:

   -- Conduct the vibration test as specified; monitor the optical transmittance for 5 sec before and after the test.

   -- Conduct a visual examination over the same area as previously inspected

5. Conduct the random vibration test on each principal axis as follows:

   -- Conduct the vibration test as specified; monitor the optical transmittance for 5 sec before and after the test; monitor the optical transmittance for a 5-sec interval every 5 min during the test

   -- Conduct a visual examination over the same area as previously inspected

<u>Post Exposure</u>

The post exposure test sequence shall be as follows:

1. Conduct a visual and mechanical inspection of the test sample over the same area as previously inspected

TEST DATA REQUIREMENTS

The test data sheets shall contain the following:

a. Title of the test

b. Date

c. Test engineer

d. Test sample identification number

e. Test instrumentation identification numbers and description

f. Data collection frequency resolution

g. Total test time

h. Ambient temperature

i. The time the following events occurred:

-- A visual or mechanical inspection made

-- Any voltage level measurement made

-- Start and end of each vibration test

j. Instrumented waveguide identification

k. Results of all the visual and mechanical inspections

l. Recorded output voltage levels for each active detector

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Vibration tests were performed on commercial grade, fiber-optic connectors and splices. Both singlemode and multimode components were tested. Sinusoidal vibrations up to 500 Hz and random vibrations up to 2000 Hz were applied. Analog modulation was negligible and no permanent damage was observed.

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